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DISCUSSION OF PAVEMENT BEARING CAPACITY COMPUTED BY THEORY OF LAYERED SYSTEMS

(*Published in May, 1950*)

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SOIL MECHANICS DIVISION

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DISCUSSION

ROBERT RUCKLI.[29]—Because they have practically no tensile strength, flexible pavements cannot be analyzed by applying the Burmister theory[4] to cases in which the ratio E_1/E_2 is small. One might expect that the difference between the moduli of elasticity E_1 and E_2 would diminish the factor of concentration ν, introduced by O. K. Fröhlich,[30] but the writer, with the help of the principle of minimum stress energy, found that the decrease is small. For a single load, a ratio $E_1/E_2 = 10$ and a depth $h = 30$ cm (1 ft), it was found $\nu = 2.82$, rather than $\nu = 3$ for the homogeneous half space.

Possibly the following procedure would lead to a more conclusive result: Instead of a discrete variation of the modulus of elasticity from E_1 to E_2 assume that E decreases, beginning at the top, in such a manner that no horizontal tensile stress occurs along the z-axis. A function $E = f(z)$ would be derived that would fulfil this condition. The pavement, base, and subbase would then be constructed so that the modulus of elasticity of the foundation would vary approximatively in accordance with the same law. In this manner, it would be possible to evaluate the degree to which the quality of the foundation (E) will influence the stress distribution in the subsoil, and therefore to compute the thickness of the pavement.

By this procedure, also, one could find an answer to the question of whether multi-layer systems really behave approximately according to the Boussinesq theory,[25] as the authors suggest in their discussion of Fig. 10. At the very best, the Boussinesq theory is not very simple, and the writer doubts that a mathematician could be found who could generalize it to the solution of this complex problem.

HUGH Q. GOLDER.[31]—Another theory for the design of pavements is offered in this paper. The method of approach would seem to be unobjectionable but, as is the case in all theories, its applicability must rest on some assumptions. In the method described by the writer and R. Glossop[11] the same was true, and one assumption—namely, that the tensile strength of the concrete was neglected—was heavily criticized. However, this method had the almost unique advantage of having been devised after the occurrence of pavement failures, against which it was then checked. The design criterion was chosen as one out of

NOTE.—This paper by Guthlac Wilson and G. M. J. Williams was published in May, 1950. The numbering of footnotes in this Separate is a continuation of the consecutive numbering used in the original paper.

[29] Rosenbergstrasse 42, Berne, Switzerland.

[4] "The Theory of Stresses and Displacements in Layered Systems and Applications to the Design of Airport Runways," by D. M. Burmister, *Proceedings*, Highway Research Board, National Research Council, Vol. 23, 1943.

[30] "Druckverteilung im Baugrunde, mit besonderer berucksichtigung der plastischen eischeinungen," by O. K. Fröhlich, Springer-Verlag, Wien, 1934, p. 23.

[25] "Runway Strength Correlation Between the Distribution of Stresses in the Soil Derived from: (1) The C. B. R. Method of the Determination of Runway Thickness; (2) the Theory of Boussinesq," by R. de l'Hortet, *Proceedings*, 2d International Conference on Soil Mechanics, Rotterdam, 1948, Vol. V, p. 185.

[31] Director, Soil Mechanics, Ltd., London, England.

[11] "Construction of Pavements on a Clay Foundation Soil," by R. Glossop and H. Q. Golder, *Road Paper No. 15*, Inst. C. E., 1944.

three, in order to give good agreement with the case of actual failure, for the conditions existing. The same criterion was later checked against other failures and found to give reasonable agreement. It was later found that the method gave good agreement with the wholly empirical California Bearing Ratio (CBR) method.

The later method for frictional materials (including materials both frictional and cohesive) devised by the writer,[24] has not been checked against the failure of pavements on a sand foundation. The reason for this is simple: The writer has been unable to discover any case in which a pavement on sand has failed due to failure of the foundation, although he has consistently asked, on every possible occasion, for information concerning such a failure.

The foregoing evidence confirms the writer's belief that the variation in thickness of slab given by the Westergaard method[8] does not reflect, accurately, the variation in the properties of the foundation material when going from, say, soft clay to a dense sand; and it does not reflect the effect of this variation on pavement behavior. Incidently, this second method can be made to agree with the Glossop-Golder method for the case of clays, simply by the choice of a suitable factor of safety.

Messrs. Wilson and Williams have made many assumptions, of which they are fully aware, and which are concerned partly with their endeavor to obtain a comparison between the different methods. In Fig. 10, for example, the Boussinesq curve takes them straight back to the original assumption of the Glossop-Golder method.

In their comparisons of the different methods (Fig. 8), Messrs. Wilson and Williams state: "Mr. Golder's method,[6] on the other hand, appears to be unsafe for the concrete would crack." Properly, they should have added "according to the Westergaard theory or the Wilson-Williams theory." As stated, the writer has yet to find a case in which the concrete did crack on a sand subgrade. Although making no claim that the Golder method gives the correct answer, the writer feels that it gives the right degree of difference between the thickness of pavement required on a dense sand and a soft clay and, to the writer's knowledge, it is the only one that does so. In discussing the writer's 1946 paper,[6] Mr. Wilson referred to a possible method such as he has now produced, stating: "the matter would certainly require to be confirmed by practical tests on a large scale, or by experience."

Although applauding the initiative and energy of the authors, the writer feels that a new method such as this should be used with reserve until it has been checked against experience with pavements designed down to a failure condition.

In Section 5, the authors state that "* * * if K_o had its minimum value, the soil could carry no load beyond its own weight." The statement that "K_o had its minimum value," is equivalent to stating that the Rankine active state of

[24] "The Relationship of Runway Thickness and Undercarriage Design to the Properties of the Subsoil," by H. Q. Golder, *Airport Paper No. 4*, Inst. C. E., 1946, p. 5, Table II.

[8] "Stresses in Concrete Pavements Computed by Theoretical Analysis," by H. M. Westergaard, *Public Roads*, April, 1926, pp. 25–35.

[6] "The Relationship of Runway Thickness and Undercarriage Design to the Properties of the Subsoil," by H. Q. Golder, *Airport Paper No. 4*, Inst. C. E., 1946.

stress exists in the ground. This means that, on all planes inclined at $45°-\phi/2$, incipient failure exists; but this is not a condition of foundation failure. As shown by W. J. M. Rankine, M. Ritter, and Karl Terzaghi, Hon. M. ASCE, in different ways, the power of a frictional material to support a load is considerable (particularly with a wide load), even when the active state is assumed below the load. In this connection it would be interesting to know how the value of K_o was measured in the test referred to, since this is a most difficult thing to do.

GUTHLAC WILSON,[32] M. ASCE, and G. M. J. WILLIAMS,[33] ASSOC. M. ASCE.—The interesting suggestion by Mr. Ruckli appears particularly applicable to flexible pavements founded on base and subbase courses of decreasing strengths on a weak subgrade.

In answer to Mr. Golder, the writers refer to Fig. 8 as a convincing demonstration that the Westergaard method is an accurate reflection of the properties of the foundation material. The thickness of concrete pavement given by the Westergaard method is consistently between 80% and 85% of the thickness given by the method presented in the paper. Lack of recorded instances of cracking in concrete pavements on sand subgrades does not necessarily support Mr. Golder's view. Rather, it is likely that all such pavements were designed by the Westergaard theory, to which they form an eloquent testimonial.

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